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SIR;

CERTIFIED TRANSLATION

I, Takahisa SATOH, am an official translator of the Japanese language into the English language and I hereby certify that the attached comprises an accurate translation into English of Japanese Application No. 2000-189729, filed on June 20, 2000.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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[Name of Object]	Summary	1

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[TITLE OF THE INVENTION] Optical Device and Method of Production of Same

[CLAIMS]

[Claim 1]

An optical device comprising

a base material made of a first optical material and

a second optical material having a different refractive index from the first optical material, wherein

the base material comprises first and second faces facing each other, a first concavity is formed in the first face and a second concavity is formed in the second face, and

the second optical material is filled in the first and second concavities.

[Claim 2]

An optical device as set forth in claim 1, wherein

the first and second concavities have rotationally symmetric or approximately rotationally symmetric shapes,

a first flat portion is formed at the area around the first concavity at the first face,

a second flat portion is formed at the area around th second concavity at the second face, and

the first and second flat portions are parallel or approximately parallel.

[Claim 3]

An optical device as set forth in claim 2, wherein

the surface of the second optical material filled in the first concavity and the first flat portion are parallel or approximately parallel, and

the surface of the second optical material filled in the second concavity and the second flat portion are parallel or approximately parallel.

[Claim 4]

An optical device as set forth in claim 3, wherein

the surface of the second optical material filled in the first concavity and the first flat portion are located in an identical plane or approximately identical plane, and

the surface of the second optical material filled in the second concavity and the second flat portion are located in an identical plane or approximately identical plane.

[Claim 5]

An optical device as set forth in claim 2, wherein

the shape of the surface of the first concavity when the first concavity is cut along its symmetry axis is an arc or approximately an arc, and

the shap of the surface of the second concavity when the s cond concavity is cut along its symm try axis

is an arc or approximately an arc.

[Claim 6]

An optical device as set forth in claim 2, wherein the symmetry axes of the first and second concavities are located on an identical straight line or approximately identical straight line.

[Claim 7]

An optical device as set forth in claim 6, wherein the first and second concavities have identical or approximately identical sizes.

[Claim 8]

An optical device as set forth in claim 1, wherein the second optical material is titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 9]

An optical device as set forth in claim 1, wherein

the second optical material is a liquid-like optical material,

a first layer made of an optical material sealing the first concavity filled with the second optical material is formed on the first face, and

a s cond layer made of an optical material sealing the second concavity filled with the s cond optical

material is form d on the second face.

[Claim 10]

An optical device as set forth in claim 6, wherein

the first and second layers have constant or approximately constant thicknesses and are made of an identical optical material,

the thickness of the first layer is identical or approximately identical to the thickness of the second layer, and

the second optical material is an optical oil or a liquid crystal.

[Claim 11]

A method for production of an optical device wherein a second optical material having a different refractive index from a first optical material is filled in a concavity of a base material made of the first optical material, comprising

a step of using a metallic mold in which projections projecting into a cavity are formed on facing walls of the cavity to mold a base material made of the first optical material formed on its facing first and second faces with concavities reproducing shapes of the projections and

a st p of filling the second optical material in the concavities of the first and second faces of the molded

bas material.

[Claim 12]

A method of production of an optical device as set forth in claim 11, further comprising a step of flattening the surface of the second optical material filled in the concavities of the first and second faces.

[Claim 13]

A method of production of an optical device as set forth in claim 12, wherein

the concavities of the facing walls have rotationally symmetric or approximately rotationally symmetric shapes, and

the flattening step has

a step of polishing the surface of the second optical material filled in the concavity of the first face so that a flat face vertical or approximately vertical with respect to a symmetry axis of the concavity of the first face with the shape of the projection formed on one wall of the facing walls transferred thereto is formed, and

a step of polishing the surface of the second optical material filled in the concavity of the second fac so that a flat face vertical or approximat ly vertical with respect to the symmetry axis of the concavity of the second face with the shape of the

projection formed on the other wall of the facing walls transferred thereto is formed.

[Claim 14]

A method of production of an optical device as set forth in claim 13, wherein the shapes of the surfaces of the projections when the projections of the facing walls are cut along symmetry axes of the related projections are arcs or approximately arcs.

[Claim 15]

A method of production of an optical device as set forth in claim 14, wherein

the symmetry axes of the projections of the facing walls are located on the identical straight line or approximately identical straight line, and

the symmetry axes of the concavities of the first and second faces are located on the identical straight line or approximately identical straight line.

[Claim 16]

A method of production of an optical device as set forth in claim 14, wherein the concavities of the first and second faces are identical or approximately identical sizes.

[Claim 17]

A method of production of an optical device as set forth in claim 11, wherein the s cond optical material is

titanium oxid , tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 18]

A method of production of an optical device as set forth in claim 11, wherein

the second optical material is a liquid-like optical material, and

the step of filling the second optical material has a step of filling the second optical material in the concavity of the first face of the molded base material and sealing the concavity of the related first face by a first layer made of the optical material and then filling the second optical material in the concavity of the second face and sealing the concavity of the related second face by a second layer made of the optical material.

[Claim 19]

A method of production of an optical device as set forth in claim 18, wherein

the first and second layers are films of constant or approximately constant thickness s, and

the second optical material is an optical oil or a liquid crystal.

[Claim 20]

A method of production of an optical device as set forth in claim 19, wherein

the first and second layers are made of an identical optical material, and

the thickness of the first layer is identical or approximately identical to the thickness of the second layer.

[Claim 21]

A method for production of an optical device wherein a second optical material having a different refractive index from a first optical material is filled in a concavity of a base material made of the first optical material, comprising

a step of forming resist films having windows on flat or approximately flat first and second faces facing each other of a base material made of the first optical material,

a step of forming concavities corresponding to the windows in the first and second faces of the base material by etching,

a step of removing the resist films from the base material with the concavities formed therein, and

a step of filling the s cond optical material in the concaviti s of the first and s cond fac s of th bas

material from which th resist films have b en remov d.

[Claim 22]

A method of production of an optical device as set forth in claim 21, further comprising a step of flattening the surface of the second optical material filled in the concavities of the first and second faces.

[Claim 23]

A method of production of an optical device as set forth in claim 22, wherein

the windows are circular or approximately circular,

the concavities have rotationally symmetric or approximately rotationally symmetric shapes, and

the flattening step has

a step of polishing the surface of the second optical material filled in the concavity of the first face so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity of the first face is formed, and

a step of polishing the surface of the second optical material filled in the concavity of the second face so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity of the second fac is formed.

[Claim 24]

A method of production of an optical devic as set

forth in claim 23, wherein

the shape of the surface of the related concavity when the concavity of the first face is cut along its symmetry axis is an arc or approximately an arc, and

the shape of the surface of the related concavity when the concavity of the second face is cut along its symmetry axis is an arc or approximately an arc.

[Claim 25]

A method of production of an optical device as set forth in claim 24, wherein the symmetry axes of the concavities of the first and second faces are located on the identical straight line or approximately identical straight line.

[Claim 26]

A method of production of an optical device as set forth in claim 24, wherein

the window of the resist film formed on the first face has an identical or approximately identical size to the window of the resist film formed on the second face, and

the concavities of the first and second faces have identical or approximately identical sizes.

[Claim 27]

A method of production of an optical device as set forth in claim 21, wherein the second optical material is

titanium oxide, tantalum oxid , niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 28]

A method of production of an optical device as set forth in claim 21, wherein

the second optical material is a liquid-like optical material, and

the step of filling the second optical material has a step of filling the second optical material in the concavity of the first face of the base material with the resist film removed therefrom and sealing the concavity of the related first face by a first layer made of the optical material and then filling the second optical material in the concavity of the second face and sealing the concavity of the related second face by a second layer made of the optical material.

[Claim 29]

A method of production of an optical device as set forth in claim 28, wherein

the first and second layers are films having constant or approximately constant thicknesses, and

the second optical mat rial is an optical oil or liquid crystal.

[Claim 30]

A method of production of an optical device as set forth in claim 29, wherein

the first and second layers are made of identical optical materials, and

the thickness of the first layer is identical or approximately identical to the thickness of the second layer.

[Claim 31]

A method for production of an optical device wherein a second optical material having a different refractive index from a first optical material is filled in a concavity of a base material made of the first optical material, comprising

a step of forming on a second base material provided with a first projection and having a flat area around the first projection a first base material made of a layer of the first optical material burying the first projection,

a step of forming on a fourth base material provided with a second projection and having a flat area around the second projection a third base material made of a layer of the first optical material burying the second projection,

a step of flattening the surface of the first base material to form a flat face and bonding the relat d flat

face to a first flat face among facing first and second flat faces of a fifth base material made of a third optical material,

a step of flattening the surface of the third base material to form a flat face and bonding the related flat face to the second flat face of the fifth base material,

a step of removing the second and fourth base materials from the first and third base materials bonded to the fifth base material and exposing concavities with the shapes of the first and second projections transferred thereto in the first and third base materials, and

a step of filling the second optical material in the concavities of the exposed first and third base materials.

[Claim 32]

A method of production of an optical device as set forth in claim 31, further comprising a step of flattening the surface of the second optical material filled in the concavities of the first and third base materials.

[Claim 33]

A method of production of an optical device as set forth in claim 32, wherein

the first and second projections have rotationally

symmetric or approximately rotationally symm tric shapes, and

the flattening step has

a step of polishing the surface of the second optical material filled in the concavity of the first base material so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity of the first base material with the shape of the first projection transferred thereto is formed and

a step of polishing the surface of the second optical material filled in the concavity of the third base material so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity of the third base material with the shape of the second projection transferred thereto is formed.

[Claim 34]

A method of production of an optical device as set forth in claim 33, wherein

the shape of the surface of the first projection when the first projection is cut along its symmetry axis is an arc or approximately an arc, and

the shape of the surfac of the second projection when the second projection is cut along its symmetry axis

is an arc or approximately an arc.

[Claim 35]

A method of production of an optical device as set forth in claim 34, wherein the symmetry axes of the concavities of the first and third base materials are located on the identical straight line or approximately identical straight line.

[Claim 36]

A method of production of an optical device as set forth in claim 34, wherein the concavities of the first and third base materials have an identical or approximately same size.

[Claim 37]

A method of production of an optical device as set forth in claim 31, wherein the first and third optical materials are identical optical materials.

[Claim 38]

A method of production of an optical device as set forth in claim 31, wherein the second optical material is titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxyg n, or silicon nitride.

[Claim 39]

A method of production of an optical device as set

forth in claim 31, wherein

the second optical material is a liquid-like optical material, and

the step of filling the second optical material has a step of filling the second optical material in the concavity of the exposed first base material and sealing the concavity of the related first base material by a first layer made of the optical material and then filling the second optical material in the concavity of the third base material and sealing the concavity of the related third base material by a second layer made of the optical material.

[Claim 40]

A method of production of an optical device as set forth in claim 39, wherein

the first and second layers are films having constant or approximately constant thicknesses, and

the second optical material is an optical oil or liquid crystal.

[Claim 41]

A method of production of an optical device as set forth in claim 39, wherein

th first and second layers are made of the identical optical material, and

the thickness of the first layer is identical or

approximat ly identical to the thickness of the second layer.

[DETAILED DESCRIPTION OF INVENTION]

[0001]

[Technical Field of the Invention]

The present invention relates to an optical device and a method of production of the same.

[0002]

[Prior Art]

When producing a lens, the following first to third methods of production have been known.

The first method of production is a method of filling an optical material in a metallic mold machined to an intended lens shape and producing the lens by simple molding.

The second method of production is a method of utilizing reactive ion etching (RIE) or other etching and using a photo resist or the like as a mask (etching mask) to etch an optical material to a predetermined shape to thereby produce a lens made of the related optical material.

The third method of production is a method of mechanically polishing a base material made of an optical material to th lens shape to produce the lens.

[0003]

[Probl ms to be Solved by the Invention]

In the conventional first method of production, that is, the method using simple molding, it is difficult to produce a small sized lens having a large numerical aperture, so it is difficult to reduce the lens diameter to 1 mm or less.

In the conventional second method of production, that is, the method using RIE or other etching, the optical material is limited, so it is difficult to use a material having a high refractive index and it is difficult to realize a lens having a large numerical aperture NA.

In the conventional third method of production, it is difficult to manufacture a small sized lens.

[0004]

If increasing the numerical aperture of the lens, it is possible to make the size of a light spot created after passing through the lens small. It is desirable from the viewpoint of increase of the capacity of an optical disc to enlarge the numerical aperture NA of the lens (object lens) of an optical head.

Also, lenses and other optical devices are being us d for various optical apparatus s. Reduction of the size of the optical devices is desirable from th vi wpoint of the reduction of size of the optical

apparatuses.

[0005]

In order to realize an optical device having a large numerical aperture, a large refractive index of the optical material is effective.

As an optical material having a high refractive index in the visible light region, there are titanium oxide, tantalum oxide, niobium oxide, gallium phosphate (gallium phosphorus), gallium nitride, silicon nitride, etc.

However, it is difficult to machine these materials to small sized lenses having a large numerical aperture in the prior art.

[0006]

Also, many conventional lenses have irregular shapes. In order to align a plurality of lenses of such irregular shapes, high precision positioning in three-dimensional directions is necessary, so the load of the alignment work is large.

Also, when comprising a flying head (floating head) consisting of an optical head mounted on a swing arm, the optical head can be prepared by separately preparing a slider and the lens and attaching them at a high precision, but in this case, the load of the attachment work and accordingly the load of preparation of th

optical head is large.

[0007]

A first object of the present invention is to provide a method of production of an optical device capable of creating a small sized optical device, a second object is to provide a method of production of an optical device capable of creating an optical device having a small size and a large numerical aperture, a third object is to provide an optical device which can be created from the methods of production, and a fourth object is to provide an optical system having the related optical device.

[0008]

[Means for Solving the Problem]

An optical device according to the present invention is an optical device comprising a base material made of a first optical material and comprising a second optical material having a different refractive index from the first optical material, wherein the base material has first and second faces facing each other, a first concavity is formed in the first face and a second concavity is formed in the second face, and the second optical material is filled in the first and second concavities.

[0009]

In the optical device according to the pres nt invention, preferably the first and second concavities have rotationally symmetric or approximately rotationally symmetric shapes, a first flat portion is formed at the area around the first concavity at the first face, a second flat portion is formed at the area around the second concavity at the second face, and the first and second flat portions are parallel or approximately parallel.

[0010]

In the optical device according to the present invention, more preferably the surface of the second optical material filled in the first concavity and the first flat portion are parallel or approximately parallel, and the surface of the second optical material filled in the second concavity and the second flat portion are parallel or approximately parallel.

In the optical device according to the present invention, for example, a configuration may be used where the surface of the second optical material filled in the first concavity and the first flat portion are located in an identical plane or approximately identical plane, and the surfac of the s cond optical material fill d in the second concavity and the second flat portion are located in an identical plane or approximately identical plane.

[0011]

In the optical device according to the present invention, more preferably the shape of the surface of the first concavity when the first concavity is cut along its symmetry axis is an arc or approximately an arc, and the shape of the surface of the second concavity when the second concavity is cut along its symmetry axis is an arc or approximately an arc.

[0012]

In the optical device according to the present invention, more preferably the symmetry axes of the first and second concavities are located on an identical straight line or approximately identical straight line.

In the optical device according to the present invention, for example, the first and second concavities may have identical or approximately identical sizes.

[0013]

In the optical device according to the present invention, for example, the second optical material can also be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxyg n, or silicon nitride.

[0014]

In the optical device according to the present

invention, pref rably the second optical material is a liquid-like optical material, a first layer made of an optical material sealing the first concavity filled with the second optical material is formed on the first face, and a second layer made of an optical material sealing the second concavity filled with the second optical material is formed on the second face.

[0015]

In the optical device according to the present invention, a configuration may be used where for example the first and second layers have constant or approximately constant thicknesses and are made of an identical optical material, the thickness of the first layer is identical or approximately identical to the thickness of the second layer, and the second optical material is an optical oil or a liquid crystal.

[0016]

A first method of production of an optical device according to the present invention is a method for production of an optical device wherein a second optical material having a different refractive index from a first optical material is filled in a concavity of a base material mad of the first optical material, comprising a step of using a metallic mold in which projections projecting into a cavity are formed on facing walls of

the cavity to mold a base material made of the first optical material formed on its facing first and second faces with concavities reproducing shapes of the projections and a step of filling the second optical material in the concavities of the first and second faces of the molded base material.

[0017]

The first method of production of an optical device according to the present invention preferably further has a step of flattening the surface of the second optical material filled in the concavities of the first and second faces.

[0018]

In the first method of production of an optical device according to the present invention, more preferably the concavities of the facing walls have rotationally symmetric or approximately rotationally symmetric shapes, and the flattening step has a step of polishing the surface of the second optical material filled in the concavity of the first face so that a flat face vertical or approximately vertical with respect to a symmetry axis of the concavity of the first face with the shape of the proj ction formed on one wall of the facing walls transferred ther to is formed, and a st p of polishing the surface of the second optical material

filled in th concavity of th second face so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity of the second face with the shape of the projection formed on the other wall of the facing walls transferred thereto is formed.

[0019]

In the first method of production of an optical device according to the present invention, more preferably the shapes of the surfaces of the projections when the projections of the facing walls are cut along symmetry axes of the related projections are arcs or approximately arcs.

[0020]

In the first method of production of an optical device according to the present invention, for example, a configuration may be used wherein the symmetry axes of the projections of the facing walls are located on the identical straight line or approximately identical straight line, and the symmetry axes of the concavities of the first and second faces are located on the identical straight line or approximately identical straight line.

In the first method of production of an optical device according to the present invention, for example, it is also possible to impart identical or approximately

id ntical sizes to the concavities of the first and second faces.

[0021]

In the first method of production of an optical device according to the present invention, for example, the second optical material may also be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0022]

In the first method of production of an optical device according to the present invention, preferably the second optical material is a liquid-like optical material, and the step of filling the second optical material has a step of filling the second optical material in the concavity of the first face of the molded base material and sealing the concavity of the related first face by a first layer made of the optical material and then filling the second optical material in the concavity of the second face and sealing the concavity of the related second face by a second layer made of the optical material.

[0023]

In the first method of production of an optical

d vice according to the present invention, for example, a configuration may be used wherein the first and second layers are films of constant or approximately constant thicknesses, and the second optical material is an optical oil or a liquid crystal.

In the first method of production of an optical device according to the present invention, for example, a configuration may be used wherein the first and second layers are made of an identical optical material, and the thickness of the first layer is identical or approximately identical to the thickness of the second layer.

[0024]

A second method of production of an optical device according to the present invention is a method for production of an optical device wherein a second optical material having a different refractive index from a first optical material is filled in a concavity of a base material made of the first optical material, comprising a step of forming resist films having windows on flat or approximately flat first and second faces facing each other of a base material made of the first optical mat rial, a st p of forming concavities corresponding to the windows in the first and second faces of the base mat rial by etching, a step of removing the resist films

from the bas mat rial with the concavities formed therein, and a step of filling the second optical material in the concavities of the first and second faces of the base material from which the resist films have been removed.

[0025]

The second method of production of an optical device according to the present invention preferably further has a step of flattening the surface of the second optical material filled in the concavities of the first and second faces.

[0026]

In the second method of production of an optical device according to the present invention, more preferably the windows are circular or approximately circular, the concavities have rotationally symmetric or approximately rotationally symmetric shapes, and the flattening step has a step of polishing the surface of the second optical material filled in the concavity of the first face so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity of the first face is formed, and a step of polishing the surfac of the second optical material filled in th concavity of the second fac so that a flat face vertical or approximately vertical with respect to

the symmetry axis of the concavity of the s cond face is formed.

[0027]

In the second method of production of an optical device according to the present invention, more preferably the shape of the surface of the related concavity when the concavity of the first face is cut along its symmetry axis is an arc or approximately an arc, and the shape of the surface of the related concavity when the concavity of the second face is cut along its symmetry axis is an arc or approximately an arc.

[0028]

In the second method of production of an optical device according to the present invention, for example, a configuration may be used wherein the symmetry axes of the concavities of the first and second faces are located on the identical straight line or approximately identical straight line.

In the second method of production of an optical device according to the present invention, for example, a configuration may be used wherein the window of the r sist film formed on the first face has an identical or approximately id ntical size to the window of the resist film formed on the second face, and the concavities of

th first and second faces have identical or approximately identical sizes.

[0029]

In the second method of production of an optical device according to the present invention, for example, the second optical material may also be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0030]

In the second method of production of an optical device according to the present invention, preferably the second optical material is a liquid-like optical material, the step of filling the second optical material has a step of filling the second optical material in the concavity of the first face of the base material with the resist film removed therefrom and sealing the concavity of the related first face by a first layer made of the optical material and then filling the second optical material in the concavity of the second face and sealing the concavity of the related second face by a second layer made of the optical material.

[0031]

In the second method of production of an optical

devic according to the present inv ntion, for example, a configuration may be used wherein the first and second layers are films having constant or approximately constant thicknesses, and the second optical material is an optical oil or liquid crystal.

In the second method of production of an optical device according to the present invention, for example, a configuration may be used wherein the first and second layers are made of identical optical materials, and the thickness of the first layer is identical or approximately identical to the thickness of the second layer.

[0032]

A third method of production of an optical device according to the present invention is a method for production of an optical device wherein a second optical material having a different refractive index from a first optical material is filled in a concavity of a base material made of the first optical material, comprising a step of forming on a second base material provided with a first projection and having a flat area around the first projection a first base material made of a layer of the first optical material burying the first projection, a step of forming on a fourth base material provid d with a second projection and having a flat area around the

s cond projection a third base material made of a layer of the first optical material burying the second projection, a step of flattening the surface of the first base material to form a flat face and bonding the related flat face to a first flat face among facing first and second flat faces of a fifth base material made of a third optical material, a step of flattening the surface of the third base material to form a flat face and bonding the related flat face to the second flat face of the fifth base material, a step of removing the second and fourth base materials from the first and third base materials bonded to the fifth base material and exposing concavities with the shapes of the first and second projections transferred thereto in the first and third base materials, and a step of filling the second optical material in the concavities of the exposed first and third base materials.

[0033]

The third method of production of an optical device according to the present invention preferably further has a step of flattening the surface of the second optical material filled in the concavities of the first and third base materials.

[0034]

In the third method of production of an optical

device according to the present invention, more preferably the first and second projections have rotationally symmetric or approximately rotationally symmetric shapes, and the flattening step has a step of polishing the surface of the second optical material filled in the concavity of the first base material so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity of the first base material with the shape of the first projection transferred thereto is formed and a step of polishing the surface of the second optical material filled in the concavity of the third base material so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity of the third base material with the shape of the second projection transferred thereto is formed.

[0035]

In the third method of production of an optical device according to the present invention, more preferably the shape of the surface of the first projection when the first projection is cut along its symmetry axis is an arc or approximately an arc, and the shape of the surface of the second projection when the second projection is cut along its symmetry axis is an arc or approximately an arc.

[0036]

In the third method of production of an optical device according to the present invention, for example, a configuration may be used wherein the symmetry axes of the concavities of the first and third base materials are located on the identical straight line or approximately identical straight line.

In the third method of production of an optical device according to the present invention, for example an identical or approximately same size can be imparted to the concavities of the first and third base materials too.

[0037]

In the third method of production of an optical device according to the present invention, preferably the first and third optical materials are identical optical materials.

[0038]

In the third method of production of an optical device according to the present invention, for example, the second optical material can also be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0039]

In the third method of production of an optical device according to the present invention, preferably the second optical material is a liquid-like optical material, and the step of filling the second optical material has a step of filling the second optical material in the concavity of the exposed first base material and sealing the concavity of the related first base material by a first layer made of the optical material and then filling the second optical material in the concavity of the third base material and sealing the concavity of the related third base material by a second layer made of the optical material.

[0040]

In the third method of production of an optical device according to the present invention, for example, a configuration may be used wherein the first and second layers are films having constant or approximately constant thicknesses, and the second optical material is an optical oil or liquid crystal.

In the third method of production of an optical device according to the present invention, for example, a configuration may be used wherein the first and second layers are made of the identical optical material, and the thickness of the first lay r is id ntical or

approximat ly identical to the thickness of the second layer.

[0041]

In the first method of production of an optical device according to the present invention, the metallic mold is formed on facing walls of the cavity with projections projecting out into the cavity. By molding the base material by this metallic mold, concavities with the shapes of the projections transferred thereto can be formed in the facing faces of the base material.

By filling the second optical material in the concavities of the base material made of the first optical material, the light can be refracted at the surfaces of the concavities due to a difference of the refractive indexes. By reducing the sizes of the projections of the metallic mold, the concavities of the base material can be made small in size and it is possible to create a small sized optical device.

Also, by providing the concavities filled with the optical material in the facing faces of the base material, it is possible to enlarge the numerical aperture of the optical device in comparison with the case wh re a concavity filled with the optical mat rial is provided in only on face of the base material.

Also, by using a mat rial having a large refractive

index as the second optical material, for example titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0042]

In the second method of production of an optical device according to the present invention, by forming resist films having windows on the facing faces of the base material made of the first optical material, concavities corresponding to the windows can be formed by etching.

By removing the resist films from the base material with the concavities formed therein and filling the second optical material in the concavities, light can be refracted at the surfaces of the concavities due to the difference of the refractive indexes. By reducing the sizes of the windows, the concavities of the base material can be made small in size and it is possible to create a small sized optical device.

Also, by providing the concavities filled with the optical mat rial in the facing faces of the base material, it is possible to enlarge the numerical aperture of the optical d vice in comparison with the

case where a concavity fill d with th optical material is provided in only one face of the base material.

Also, by using a material having a large refractive index as the second optical material, for example, titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0043]

In the third method of production of an optical device according to the present invention, the second and fourth base materials are provided with projections and the areas around the related projections are flat. By forming on the second base material the first base material made of a layer of the first optical material burying the projection and forming on the fourth base material the third base material made of a layer of the first optical material burying the projection, concavities with the shapes of the projections transferred thereto can be formed in the first and third base materials.

By flattening the surfaces of the first and third base materials to form the flat faces, bonding th r lat d flat faces to the facing faces of the fifth base

material made of the third optical material, and removing the second and fourth base materials from the first and third base materials bonded to the fifth base material, concavities with the shapes of the projections transferred thereto in the first and third base materials can be exposed.

By filling the second optical material in the concavities of the first and third base materials, light can be refracted at the surfaces of the concavities due to the difference of the refractive indexes. By reducing the sizes of the projections of the second and fourth base materials, the concavities of the first and third base materials can be made small in size and it is possible to create a small sized optical device.

Also, the first and third base materials bonded to the fifth base material have concavities filled with the optical materials, therefore it is possible to enlarge the numerical aperture in comparison with the case where only one of the first or third base material is bonded to the fifth base material.

Also, by using a material having a large refractive index as the second optical material, for example, titanium oxid , tantalum oxid , niobium oxide, gallium phosphate, gallium nitrid , a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum,

and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0044]

[Embodiments of the Invention]

Below, embodiments of the present invention will be explained by referring to the attached drawings.

[0045]

Optical Device

Figure 1 is a schematic view of the configuration of an embodiment of an optical device according to the present invention.

This optical device 100 has a parallelopiped or approximately parallelopiped shape. The optical device 100 has a base material (substrate) 101 and lenses 102 and 103.

The base material 101 and the lenses 102 and 103 of the optical device 100 have different refractive indexes. Light can be refracted at boundaries of the base material 101 and the lenses 102 and 103. For example, when light enters the flat face of the lens 103, a beam emitted from the flat face of the lens 102 can be converged (collected) or scattered or can be changed to a parallel beam.

[0046]

The base material 101 has a rotationally symmetric

or approximately rotationally symmetric concavity 101B in a lower face 100B of the base material 101. The shape of the surface of the concavity 101B when the concavity 101B is cut along its symmetry axis is preferably made an arc or approximately an arc.

The concavity 101B is filled with an optical material having a different refractive index from the base material 101. The lens 102 is comprised by the concavity 101B filled with the related optical material.

Also, a convex curved face of the lens 102 tightly contacts the surface of the concavity 101B of the base material 101.

[0047]

The lower face of the lens 102 is flat or approximately flat and is parallel or approximately parallel to an upper face of the optical device 100 (or an upper face 100U of the base material 101). Also, the lower face of the lens 102 and the flat portion 101C of the lower face 100B of the base material 101 are parallel or approximately parallel and located in an identical plane in Fig. 1.

[0048]

The base mat rial 101 has a rotationally symmetric or approximately rotationally symmetric concavity 101D in an upp r face 100U of the base material 101. The shape of

the surface of the concavity 101D when the concavity 101D is cut along its symmetry axis is preferably made an arc or approximately an arc.

The concavity 101D is filled with an optical material having a different refractive index from the base material 101. The lens 103 is comprised by the concavity 101D filled with the related optical material.

Also, the convex curved face of the lens 103 tightly contacts the surface of the concavity 101D of the base material 101.

[0049]

The upper face of the lens 103 is flat or approximately flat and is parallel or approximately parallel to the lower face of the optical device 100 (or the lower face 100B of the base material 101). Also, the upper face of the lens 103 and a flat portion 101E of the upper face 100U of the base material 101 are parallel or approximately parallel, and located in an identical plane in Fig. 1.

[0050]

The symmetry axes of the concavities 101B and 101D of the base material 101 are located on the identical straight line or approximately identical straight line. Contrary to this, th optical axes of the lenses 102 and 103 are located on the identical straight line or

approximately identical straight line. Th lenses 102 and 103 are preferably given identical or approximately the same sizes.

[0051]

When the material of the base material 101 is made for example quartz and the material of the lenses 102 and 103 is made for example silicon nitride, the lenses 102 and 103 have larger refractive indexes than the base material 101, so a function of a convex lens can be imparted to the lenses 102 and 103.

Conversely, when the material of the base material 101 is made for example silicon nitride and the material of the lenses 102 and 103 is made for example quartz, the lenses 102 and 103 have smaller refractive indexes than the base material 101, so the function of a concave lens can be imparted to the lenses 102 and 103.

[0052]

<u>First Embodiment of Method of Production of Optical Device</u>

Figure 2 and Fig. 3 are schematic explanatory views of a first embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical structure or approximat ly id ntical structure to the optical device 100 of Fig. 1.

[0053]

Figure 2(A) shows a metallic mold 3. In this metallic mold 3, a passageway 4 for passing a liquid-like or fluid-like optical material 6L and a cavity 3C are formed. Also, in the cavity 3C of the metallic mold 3, a lower inner wall and an upper inner wall face each other, a projection 5 projecting out into the cavity 3C is formed on the lower inner wall, a projection 5A projecting out into the cavity 3C is formed on the upper inner wall, and the areas around the projections 5 and 5A are flat.

[0054]

The projection 5 has an identical or approximately identical shape to the lens 102 of the optical device 100 of Fig. 1 and has a rotationally symmetric or approximately rotationally symmetric shape.

Also, the projection 5A has an identical or approximately identical shape to the lens 103 of the optical device 100 of Fig. 1 and has a rotationally symmetric or approximately rotationally symmetric shape.

The symmetry axes of the projections 5 and 5A are located on the identical straight line or approximately identical straight lin .

[0055]

In Fig. 2(B), the optical material 6L is injected

into the cavity 3C from the passageway 4 of the metallic mold 3, and the optical material 6 is filled in the cavity 3C. The optical material 6L injected is made for example molten quartz, a plastic, or a synthetic resin.

[0056]

In Fig. 2(C), the liquid-like optical material 6L is hardened to a solid-state optical material 6M, and a base material 6 made of the optical material 6M is taken out from the metallic mold 3.

The shape of the projection 5 is transferred to the lower face of the base material 6 taken out from the metallic mold 3 to form a concavity 6B. The concavity 6B has a symmetric or approximately symmetric shape. The area around the concavity 6B of the base material 6 is flat.

Also, the shape of the projection 5A is transferred to the upper face of the base material 6 to form a concavity 6U. The concavity 6U has a symmetric or approximately symmetric shape. The area around the concavity 6U of the base material 6 is flat.

The symmetry axes of the concavities 6B and 6U of the base material 6 are located on the identical straight line or approximately identical straight lin .

[0057]

In Fig. 3(D), an optical material 7M is filled in

the concavity 6B of the low r face of the base mat rial 6. The optical material 7M has a different refractive index from the optical material 6M, preferably has a larger refractive index than the optical material 6M, and is made silicon nitride as an example.

For example, by forming a layer 7 of the optical material 7M on the lower face of the base material 6 by sputtering, vapor deposition, or ion implantation, the optical material 7M is filled in the concavity 6B of the base material 6. In this case, a concavity 7B corresponding to the concavity 6B is formed in the layer 7.

[0058]

Also, an optical material 71M is filled in the concavity 6U of the upper face of the base material 6. This optical material 71M is preferably made an identical material to the optical material 7M.

For example, by forming a layer 71 of the optical material 71M on the upper face of the base material 6 by sputtering, vapor deposition, or ion implantation, the optical material 71M is filled in the concavity 6U of the base material 6. In this case, a concavity 71U corr sponding to the concavity 6U is form d in the layer 71.

Not that, it is also possible to fill the optical

mat rial 7M in the concavities 6B and 6U of the base material 6 by making the optical materials 7M and 71M identical material and forming the layers 7 and 71 of the optical material 7M on the upper and lower faces of the base material 6 by vapor deposition.

[0059]

In Fig. 3(E), the lower face (bottom face) of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the lower face of the layer 7 disappears. Preferably, the lower face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 6B of the base material 6 is formed. Alternatively, the layer 7 is polished so that the flat portion (or flat face) at the area around the concavity 6B of the base material 6 and the lower face of the layer 7 become parallel or approximately parallel.

[0060]

Also, the upper face of the layer 71 is flattened. For example, it is polished so that the concavity 71U of the upper face of the layer 71 disappears. Preferably, the upper face of the layer 71 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 6U of the base material 6 is formed. Alt rnatively, the layer 71 is polished so that the flat portion (or flat face) at th area around the concavity

6U of th base mat rial 6 and the upper face of the layer 71 become parallel or approximately parallel.

[0061]

By polishing the layers 7 and 71 so that the flat portions at the areas around the concavities 6B and 6U of the base material 6 are exposed, it is possible to obtain an optical device having an same structure as that of the optical device 100 of Fig. 1.

Note that, the base material 6 and the concavities 6B and 6U of Fig. 3(E) correspond to the base material 101 and the concavities 101B and 101D of the optical device 100 of Fig. 1.

[0062]

The upper and lower inner walls of the metallic mold 3 have projections 5 and 5A projecting out into the cavity 3C, so the processing precision can be improved in comparison with the case where a concavity having a sunken shape is formed in the cavity 3C and a convex lens is formed by simple molding. In this way, by using the metallic mold 3, it is possible to prepare a small sized convex lens having a higher processing precision than a convex lens obtained by simple molding.

[0063]

Note that it is also possible t perform the molding by using an upper mold and a lower mold in place of the

mold shown in Figs. 2(A) and 2(B). A proj ction is formed at the inner wall on the lower side of the lower mold, and the area around this projection is made flat. This projection is identical to the projection 5 of Figs. 2(A) and 2(B). A projection is also formed at the inner wall on the lower side of the upper mold, and the area around this projection is flat. This projection is identical to the projection 5A of Figs. 2(A) and 2(B).

[0064]

First, by injecting an optical material (for example a glass material) into the cavity between the upper mold and the lower mold and simultaneously heating the glass material, lower mold, and upper mold to a predetermined temperature, the glass material is softened. Then, the softened glass material is pressed by the upper mold. In this case, the symmetry axes of the concavities on the inner walls of the upper mold and the lower mold are located on the identical straight line or approximately identical straight line.

[0065]

Next, the glass material, lower mold, and upper mold are cooled to harden the glass material and the base material 6 is taken out from th metallic molds. The shape of the projection 5 is transferred to the low r face of this base mat rial 6 tak n out from the m tallic

molds to form the concavity 6B, while the shape of the projection 5A is transferred to the upper face of the base material 6 to form the concavity 6U.

In this way, it is also possible to obtain the base material 6 shown in Fig. 2(C).

[0066]

Second Embodiment of Method of Production of Optical Device

Figure 4 and Fig. 5 are schematic explanatory views of a second embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0067]

In Fig. 4(A), a resist 9 is formed on the flat face of a silicon substrate 8 - an example of the base material. The size of the bottom face of the resist 9 is made identical or approximately identical to the size of the flat faces of the lenses 102 and 103 in Fig. 1.

[0068]

In Fig. 4(B), a projection 8U is formed at the surface of the silicon substrate 8 by etching using the r sist 9 as the mask. The shap of the projection 8U is identical to the shapes of th lens s 102 and 103 and is

rotationally symmetric or approximately rotationally symmetric. As the etching, use is made of for example ion milling or RIE.

[0069]

In Fig. 4(C), an optical material 10M is laminated on the surface of the silicon substrate 8 formed with the projection 8U so as to bury the projection 8U and thereby form a base material made of a layer 10 of the optical material 10M. It is also possible to form the layer 10 by using for example sputtering, vapor deposition, or ion implantation.

When the layer 10 is formed on the silicon substrate 8, a projection 10U corresponding to the projection 8U is formed on the upper face of the layer 10.

[0070]

In Fig. 4(D), the upper face of the layer 10 is flattened. For example, it is polished so that the projection 10U of the upper face of the layer 10 disappears and thereby to form a flat face 10S. Preferably, the upper face of the layer 10 is polished so that a flat face vertical with respect to the symmetry axis of the projection 8U of the silicon substrate 8 is formed. Alternatively, th layer 10 is polished so that the flat portion at the area around the projection 8U of the silicon substrate 8 and the upp r face of the layer

10 b com parallel or approximately parallel.

In this way, a plurality of silicon substrates 8 and layers 10 shown in Fig. 4(D) are created.

[0071]

In Fig. 4(E), a flat face $10S_1$ of a layer 10_1 is bonded to the flat face on a lower side of the base material 11 with the facing flat faces formed thereon. Also, a flat face $10S_2$ of a layer 10_2 is bonded to an upper side flat face of the base material 11. Projections $8U_1$ and $8U_1$ are located on the identical straight line or approximately identical straight line.

Note that silicon substrates 8_1 and 8_2, projections $8U_1$ and $8U_2$, layers 10_1 and 10_2, and the flat faces $10S_1$ and $10S_2$ have the same configurations as those of the corresponding silicon substrate 8, projection 8U, layer 10, and surface 10S of Fig. 4(D).

[0072]

Also, as the bonding method of the upper and lower flat faces of the base material 11 and the flat face $10S_1$ and $10S_2$ of the layers 10_1 and 10_2, it is possible to bond by for example a transparent adhesive or possible to bond by anodic bonding. The optical material 11M of the base material 11 is preferably mad th same mat rial as the optical material 10M.

[0073]

In Fig. 5(F), the silicon substrate 8_1 bonded to the lower face of the layer 10_1 of Fig. 4(E) is removed to expose the lower face of the layer 10_1. Also, the silicon substrate 8_2 bonded to the lower face of the layer 10_2 of Fig. 4(E) is removed to expose the upper face of the layer 10_2.

Note that, it is also possible to dissolve and remove the silicon substrates 8_1 and 8_2 by for example an aqueous solution of potassium hydroxide.

[0074]

The shape of the projection $8U_1$ of the silicon substrate 8_1 is transferred to the lower face of the layer 10_1 to form the concavity $10B_1$ corresponding to the projection $8U_1$. The concavity $10B_1$ has a rotationally symmetric or approximately rotationally symmetric shape.

The shape of the projection $8U_2$ of the silicon substrate 8_2 is transferred to the upper face of the layer 10_2 to form the concavity $10B_2$ corresponding to the projection $8U_2$. The concavity $10B_2$ has a rotationally symmetric or approximately rotationally symmetric shape.

The symmetry axes of the concavities $10B_1$ and $10B_2$ are located on the identical straight line or approximately identical straight line.

[0075]

In Fig. 5(G), the optical material 7M is filled in

the concavity $10B_1$ of th lower fac of the lay r 10_1. The optical material 7M has a different refractive index from the optical material 10M, preferably has a larger refractive index than the optical material 10M. Silicon nitride is used as an example.

For example, by forming the layer 7 of the optical material 7M on the lower face of the layer 10_1 by sputtering, vapor deposition, or ion implantation, the optical material 7M is filled in the concavity $10B_1$ of the layer 10_1. In this case, a concavity 7B corresponding to the concavity $10B_1$ is formed in the layer 7.

[0076]

Also, the optical material 71M is filled in the concavity $10B_2$ of the upper face of the layer 10_2. The optical material 71M is preferably made the same material as the optical material 7M.

For example, by forming the layer 71 of the optical material 71M on the upper face of the layer 10_2 by sputtering, vapor deposition, or ion implantation, the optical material 71M is filled in the concavity $10B_2$ of the layer 10_2. In this case, a concavity 71U corresponding to the concavity $10B_2$ is formed in the layer 71.

Note that, it is also possible to fill the optical material 7M in the concavities $10B_1$ and $10B_2$ of the bas

mat rials 10_1 and 10_2 by making the optical materials 7M and 71M the identical material and forming the layers 7 and 71 of the optical material 7M on the lower face of the base material 10_1 and the upper face of the base material 10_2 by vapor deposition.

[0077]

In Fig. 5(H), the lower face (bottom face) of the layer 7 is flattened. For example, it is polished so that the concavity 7B in the lower face of the layer 7 disappears. Preferably, the lower face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity $10B_1$ of the layer 10_1 is formed. Alternatively, the layer 7 is polished so that the flat portion (or flat face) at the area around the concavity $10B_1$ of the layer 10_1 and the lower face of the layer 7 become parallel or approximately parallel.

[0078]

Also, the upper face of the layer 71 is flattened. For example, it is polished so that the concavity 71U of the upper face of the layer 71 disappears. Preferably, the upper face of the layer 71 is polished so that a flat face vertical with respect to the symmetry axis of the concavity $10B_2$ of the layer 10_2 is formed. Alt rnatively, the layer 71 is polished so that the flat portion (or flat face) at the area around the concavity $10B_2$ of the

layer 10_2 and the upper face of the layer 71 become parallel or approximately parallel.

[0079]

By polishing the layers 7 and 71 so that the flat portions at the area around the concavities $10B_1$ and $10B_2$ of the layers 10_1 and 10_2 are exposed, it is possible to obtain an optical device having an identical structure or approximately identical structure to the optical device 100 of Fig. 1.

Note that, the base material 11 with the layers 10_1 and 10_2 of Fig. 5(H) bonded thereto and the concavities $10B_1$ and $10B_2$ correspond to the base material 101 and the concavities 101B and 101D of the optical device 100 of Fig. 1.

[0080]

<u>Third Embodiment of Method of Production of Optical Device</u>

Figure 6 and Fig. 7 are schematic explanatory views of a third embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0081]

In Fig. 6(A), a resist 19 is formed at the flat face

of a silicon substrat 18 - an xample of the bas material. The size of the bottom face of the resist 19 is made identical or approximately identical to the sizes of the flat faces of the lenses 102 and 103 in Fig. 1.

[0082]

In Fig. 6(B), an optical material 20M is laminated on the surface of the silicon substrate 18 formed with the resist 19 to bury the resist 19 and thereby to form a base material made of a layer 20 of the optical material 20M. It is also possible to form the layer 20 of the optical material 20M by using for example sputtering, vapor deposition, or ion implantation. It is also possible to use for example aluminum oxide as the optical material 20M.

When the layer 20 is formed on the silicon substrate 18, a projection 20U in accordance with the resist 19 is formed on the surface of the layer 20.

[0083]

In Fig. 6(C), the upper face of the layer 20 is flattened. For example, it is polished so that a projection 20U of the upper face of the layer 20 disappears to form a flat face 20S. Preferably, the upper face of the layer 20 is polished so that a flat face vertical with resp ct to the symmetry axis of the resist 19 on the silicon substrat 18 is formed. Alternatively,

the lay r 20 is polished so that the flat portion (or flat face) at the area around the resist 19 on the silicon substrate 18 and the upper face of the layer 20 become parallel or approximately parallel.

In this way, a plurality of silicon substrates 18 and layers 20 shown in Fig. 6(C) are created.

[0084]

In Fig. 6(D), a flat face $20S_1$ of a layer 20_1 is bonded to the flat face on the lower side of the base material 21 having the facing flat faces. Also, a flat face $20S_2$ of a layer 20_2 is bonded to the flat face on the upper side of a base material 21. The symmetry axes of resists 19_1 and 19_2 are located on the identical straight line or approximately identical straight line.

Note that, the silicon substrates 18_1 and 18_2, resists 19_1 and 19_2, layers 20_1 and 20_2, and flat faces $20S_1$ and $20S_2$ have same configurations as those of the corresponding silicon substrate 18, resist 19, layer 20, and flat face 20S of Fig. 6(C).

[0085]

Also, as the bonding method of the upper and lower flat faces of the base material 21 and the flat faces $20S_1$ and $20S_2$ of the layers 20_1 and 20_2, for example, it is possible to bond by a transparent adhesive or possibl to bond by anodic bonding. An optical material 21M of the

bas material 21 is pr ferably made th same material as the optical material 20M.

[0086]

In Fig. 7(E), the silicon substrate 18_1 and the resist 19_1 bonded to the lower face of the layer 20_1 of Fig. 6(D) are removed to expose the lower face of the layer 20_1. Also, the silicon substrate 18_2 and the resist 19_2 bonded to the lower face of the layer 20_2 of Fig. 6(D) are removed to expose the lower face of the layer 20_2.

Note that it is also possible to dissolve and remove the silicon substrates 18_1 and 18_2 by for example an aqueous solution of potassium hydroxide. It is also possible to dissolve and remove the resists 19_1 and 19_1 by for example a resist use peeling solution or an organic solvent (for example acetone).

[0087]

The shape of the resist 19_1 is transferred to the lower face of the layer 20_1 to form a concavity $20B_1$ corresponding to the shape of the resist 19_1. The concavity $20B_1$ has a symmetric or approximately symmetric shape.

Also, the shape of th resist 19_2 is transferred to the upper face of the lay r 20_2 to form a concavity $20B_2$ corresponding to the shape of the resist 19_2. The

concavity $20B_2$ has a symmetric or approximately symmetric shape.

The symmetry axes of the concavities $20B_1$ and $20B_2$ are located on the identical straight line or approximately identical straight line.

[0088]

In Fig. 7(F), the optical material 7M is filled in the concavity $20B_1$ of the lower face of the layer 20_1. The optical material 7M has a different refractive index from the optical material 20M, preferably has a larger refractive index than the optical material 20M. Silicon nitride is used as an example.

For example, by forming the layer 7 of the optical material 7M on the lower face of the layer 20_1 by sputtering, vapor deposition, or ion implantation, the optical material 7M is filled in the concavity $20B_1$ of the layer 20_1. In this case, a concavity 7B corresponding to the concavity $20B_1$ is formed in the layer 7.

[0089]

Also, the optical material 71M is filled in the concavity $20B_2$ of the layer 20_2. The optical material 71M is preferably made the same material as the optical material 7M.

For example, by forming the layer 71 of the optical material 71M on the upp r face of the layer 20_2 by

sputtering, vapor deposition, or ion implantation, the optical material 71M is filled in the concavity $20B_2$ of the layer 20_2. In this case, a concavity 71U corresponding to the concavity $20B_2$ is formed in the layer 7.

Note that, it is also possible to fill the optical material 7M in the concavities $20B_1$ and $20B_2$ of the base materials 20_1 and 20_2 by making the optical materials 7M and 71M identical materials and forming the layers 7 and 71 of the optical material 7M on the lower face of the base material 20_1 and the upper face of the base material 20_2 by vapor deposition.

[0090]

In Fig. 7(G), the lower face (bottom face) of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the lower face of the layer 7 disappears. Preferably, the upper face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity $20B_1$ of the layer 20_1 is formed. Alternatively, the layer 7 is polished so that the flat portion (or flat face) at the area around the concavity $20B_1$ of the layer 20_1 and the upper face of the layer 7 b come parallel or approximat ly parall 1.

[0091]

Also, the upper face of the layer 71 is flattened.

For example, it is polished so that the concavity 71U of the upper face of the layer 71 disappears. Preferably, the upper face of the layer 71 is polished so that a flat face vertical with respect to the symmetry axis of the concavity $20B_2$ of the layer 20_2 is formed. Alternatively, the layer 71 is polished so that the flat portion (or flat face) at the area around the concavity $20B_2$ of the layer 20_2 and the bottom face of the layer 71 become parallel or approximately parallel.

[0092]

By polishing the layer 7 so that the flat portions at the area around the concavities $20B_1$ and $20B_2$ of the layers 20_1 and 20_2 are exposed, it is possible to obtain an optical device having an identical structure or approximately identical structure to the optical device 100 of Fig. 1.

Note that the base material 21 with the layers 20_1 and 20_2 of Fig. 7(G) bonded thereto and the concavities $20B_1$ and $20B_2$ correspond to the base material 101 and the concavities 101B and 101D of the optical device 100 of Fig. 1.

[0093]

<u>Fourth Embodiment of Method of Production of Optical Device</u>

Figur 8 and Fig. 9 are schematic explanatory views

of a fourth embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0094]

In Fig. 8(A), a resist 29 is formed on the flat face between facing flat faces of a base material 31 made of an optical material 31M. Also, a resist film 39 is formed on the other flat face of the base material 31. The optical material 31M is made for example quartz.

A circular or approximately circular window 29H is formed in the resist film 29 on one flat face of the base material 31, and a circular or approximately circular window 39H is formed in the resist film 39 on the other flat face of the base material 31. The windows 29H and 39H have identical or approximately identical sizes, and the center axes of the windows 29H and 39H are located on the identical straight line or approximately identical straight line. As illustrated, the windows 29H and 39H comprise holes and/or opening portions of the resist films 29 and 39.

[0095]

In Fig. 8(B), the base material 31 with the resist films 29 and 39 formed thereon is immersed in an etching

solution 32 for a pred termined tim . The etching solution 32 is composed of for example a fluoric acid solution corroding quartz.

By immersing the base material 31 in the etching solution 32 for a predetermined time, the base material 31 is gradually corroded from the windows 29H and 39H of the resist films 29 and 39, and a concavity 31U corresponding to the window 29 and a concavity 31B corresponding to the window 39 are formed in the upper and lower faces of the base material 31. The sizes of the concavities 31B and 31U are made identical or approximately identical to the sizes of the lenses 102 and 103 in Fig. 1. The concavities 31B and 31U have symmetric or approximately symmetric shapes, and the symmetry axes of the concavities 31B and 31U are located on the identical straight line or approximately identical straight line.

[0096]

In Fig. 9(C), the base material 31 is taken out from the etching solution 32, and the resist films 29 and 39 are removed. It is also possible to dissolve and remove the resist films 29 and 39 by a resist use peeling solution or an organic solvent (for example aceton), etc.

[0097]

In Fig. 9(D), the optical material 7M is filled in the concavity 31B of the lower face of the base material 31. The optical material 7M has a different refractive index from the optical material 31M, preferably has a larger refractive index than the optical material 31M. Silicon nitride is used as an example.

For example, by forming the layer 7 of the optical material 7M on the lower face of the base material 31 by sputtering, vapor deposition, or ion implantation, the optical material 7M is filled in the concavity 31B of the lower face of the base material 31. In this case, a concavity 7B corresponding to the concavity 31B is formed in the layer 7.

[0098]

Also, the optical material 71M is filled in the concavity 31U of the upper face of the base material 31. The optical material 71M is preferably made the same material as the optical material 7M.

For example, by forming the layer 71 of the optical material 71M on the upper face of the base material 31 by sputtering, vapor deposition, or ion implantation, the optical material 71M is filled in the concavity 31U of the upp r face of th base material 31. In this case, a concavity 71U corresponding to the concavity 31U is form d in the layer 71.

Note that it is also possible to fill the optical material 7M in the concavities 31B and 31U of the base material 31 by making the optical materials 7M and 71M the identical material and forming the layers 7 and 71 of the optical material 7M on the upper and lower faces of the base material 31 by vapor deposition.

[0099]

In Fig. 9(E), the lower face of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the lower face of the layer 7 disappears. Preferably, the lower face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 31B of the base material 31 is formed. Alternatively, the layer 7 is polished so that the flat portion (or flat face) at the area around the concavity 31B of the base material 31 and the lower face of the layer 7 become parallel or approximately parallel.

[0100]

Also, the upper face of the layer 71 is flattened. For example, it is polished so that the concavity 71U of the upper face of the layer 71 disappears. Preferably, the upper face of the layer 71 is polished so that a flat fac vertical with respect to the symmetry axis of the concavity 31U of the base material 31 is formed. Alt rnatively, the layer 71 is polished so that the flat

portion (or flat face) at the area around the concavity 31U of the base material 31 and the upper face of the layer 71 become parallel or approximately parallel.

[0101]

By polishing the layers 7 and 17 so that the flat portions at the area around the concavities 31B and 31U of the base material 31 are exposed, it is possible to obtain an optical device having an identical structure or approximately identical structure to the optical device 100 of Fig. 1.

Note that, the base material 31 and the concavities 31B and 31U of Fig. 9(E) correspond to the base material 101 and the concavities 101B and 101D of the optical device 100 of Fig. 1.

[0102]

<u>Fifth Embodiment of Method of Production of Optical Device</u>

Figure 10 is a schematic explanatory view of a fifth embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical structure or approximately identical structure to the optical device 100 of Fig. 1.

[0103]

A bas material 41 of Fig. 10(A) has a concavity 41B

in one face between the facing faces and has a concavity 41U in the other face. The concavities 41B and 41U have rotationally symmetric or approximately rotationally symmetric shapes, and the symmetry axes of the concavities 41B and 41U are located on the identical straight line or approximately identical straight line. The areas around the concavities 41B and 41U in the base material 41 are flat. The base material 41 is made of an optical material 41M.

The sizes of the concavities 41B and 41U are identical or approximately identical to the sizes of the lenses 102 and 103 in Fig. 1.

As this base material 41, use is made of for example the base material 6 in Fig. 2(C), the base material 11 with the layers 10_1 and 10_2 bonded thereto in Fig. 5(F), or the base material 31 in Fig. 9(C).

[0104]

In Fig. 10(B), an optical material 27M having a different refractive index from the optical material 41M is filled in the concavity 41B of the lower face of the base material 41.

As an example, when the optical material 41M is not quartz, by using gelat d quartz as th optical mat rial 27M and coating the same on the lower face of the base material 41, a layer 27 of the optical material 27M is

formed, and th optical material 27M is filled in the concavity 41B of the lower face of the base material 41.

[0105]

An optical material 37M is filled in the concavity 41U of the upper face of the base material 41. By coating the optical material 37M on the upper face of the base material 41, a layer 37 of the optical material 37M is formed, and the optical material 37M is filled in the concavity 41U of the upper face of the base material 41. The optical material 37M is made an identical material as the optical material 27M.

Then, the base material 41 with the optical materials 27M and 37M filled in the concavities 41B and 41U is heated to harden the optical materials 27M and 37M.

[0106]

In Fig. 10(C), the surface of the hardened layer 27 is flattened. For example, it is polished so that surface roughness or undulation of the lower face of the optical material 27M disappears. Preferably, the lower face of the layer 27 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 41B of the bas material 41 is formed. Alternatively, the layer 27 is polished so that the flat portion (or flat face) at the area around the concavity 41B of the base material 41

and the upp r face of the layer 27 become parallel or approximately parallel.

[0107]

Also, the surface of the hardened layer 37 is flattened. For example, it is polished so that surface roughness or undulation of the upper face of the optical material 37M disappears. Preferably, the upper face of the layer 37 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 41U of the base material 41 is formed. Alternatively, the layer 37 is polished so that the flat portion (or flat face) at the area around the concavity 41U of the base material 41 and the upper face of the layer 37 become parallel or approximately parallel.

[0108]

By polishing the layers 27 and 37 so that the flat portions at the area around the concavities 41B and 41U of the base material 41 are exposed, it is possible to obtain an optical device having an identical structure or approximately identical structure to the optical device 100 of Fig. 1.

Note that the base material 41 and the concavities 41B and 41U of Fig. 10(C) correspond to the base material 101 and th concaviti s 101B and 101D of the optical device 100 of Fig. 1.

[0109]

Sixth Embodiment of Method of Production of Optical Device

Figure 11 is a schematic explanatory view of a sixth embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical structure or approximately identical structure to the optical device 100 of Fig. 1.

[0110]

A base material 51 of Fig. 11(A) has a concavity 51B in one face among the facing faces and has a concavity 51U in the other face. The concavities 51B and 51U have rotationally symmetric or approximately rotationally symmetric shapes, and the symmetry axes of the concavities 51B and 51U are located on the identical straight line or approximately identical straight line. The areas around the concavities 51U and 51B in the base material 51 are flat. The base material 51 is made of an optical material 51M.

The sizes of the concavities 51U and 51B are identical to the sizes of the lenses 102 and 103 in Fig. 1.

As this base material 51, use is made of for example the base material 6 in Fig. 2(C), the base material 11

with the layers 10_1 and 10_2 bonded thereto in Fig. 5(F), or the base material 31 in Fig. 9(C).

[0111]

In Fig. 11(B), a liquid-like optical material 47A having a different refractive index from the optical material 51M is filled in the concavity 51B of one face of the base material 51. As the optical material 47A, use is made of an optical liquid for example an optical oil or liquid crystal.

Then, a layer 47 made of the optical material 47M is formed on one face of the base material 51, and the concavity 51B filled with the optical material 47A is sealed by the layer 47. In this way, the liquid-like optical material 47A can be filled in the concavity 51B.

[0112]

Next, a liquid-like optical material 57A is filled in the concavity 51U of the other face of the base material 51. This optical material 57A is made the same material as the optical material 47A.

Then, a layer 57 made of the optical material 57M is formed on the upper face of the base material 51, and the concavity 51U filled with the optical material 57A is sealed by the layer 57. In this way, the liquid-like optical material 57A can be filled in th concavity 51U.

The layers 47 and 57 are preferably made films

having constant or approximately constant thicknesses. Also, preferably the optical materials 47M and 57M of the layers 47 and 57 are made the same materials, and the thickness of the layer 47 is made identical or approximately identical to the thickness of the layer 57.

Note that the base material 51 and the concavities 51B and 51U of Fig. 11(B) correspond to the base material 101 and the concavities 101B and 101D of the optical device 100 of Fig. 1.

[0113]

Note that the refractive index of the glass used in the mold lens is 1.4 to 1.7 as an example.

As the optical material of the optical device according to the present invention, particularly an optical material having a large refractive index (or high refractive index) filled in the concavity of the base material, use can be made of for example aluminum oxide (Al_2O_3 having a refractive index of for example about 1.8), titanium oxide (TiO_2 having a refractive index of for example about 2.5), tantalum oxide (Ta_2O_5 having a refractive index of about 2.4), or gallium phosphate (GaP having a refractive index of for example about 3.3). By using the above optical materials, an optical device having a large numerical apertur can b prepared.

[0114]

Also, as the optical material of the optical device according to the present invention, particularly the optical material filled in the concavity of the base material, use can be made of compounds such as $Ta_{X1}O_{Y1}$, $Ti_{X2}O_{Y2}$, $Al_{X3}O_{Y3}$, $Si_{X4}O_{Y4}$, $Si_{X5}N_{Y5}$, $Mg_{X6}F_{Y6}$, $Ga_{X7}N_{Y7}$, $Ga_{X8}P_{Y8}$, $Ti_{X9}Nb_{Y9}O_{Z9}$, $Ti_{Z6}Ta_{Z7}O_{Z8}$, and $Nb_{Z4}O_{Z5}$. Note X1 to X9, Y1 to Y9 and Z6 to Z9 are numerals enabling the above compounds.

Note that the above embodiments are illustrations of the present invention. The present invention is not limited to the above embodiments.

[0115]

[Effects of the Invention]

As explained above, according to the method of production of an optical device according to the present invention, it is possible to prepare a small sized optical device. Also, according to the method of production of an optical device according to the present invention, it is possible to prepare an optical device having a small size and large numerical aperture.

Also, according to the present invention, an optical device which can be prepared from the above method of production and an optical system using the related optical device can b provid d.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

A sch matic view of the configuration of an embodiment of an optical device according to the present invention.

[Fig. 2]

A schematic explanatory view of a first embodiment of a method of production of an optical device according to the present invention.

[Fig. 3]

A schematic explanatory view of the first embodiment of the method of production of an optical device according to the present invention continued from Fig. 2.

[Fig. 4]

A schematic explanatory view of a second embodiment of the method of production of an optical device according to the present invention.

[Fig. 5]

A schematic explanatory view of the second embodiment of the method of production of an optical device according to the present invention continued from Fig. 4.

[Fig. 6]

A schematic explanatory view of a third embodiment of the method of production of an optical device according to the present invention.

[Fig. 7]

A schematic explanatory view of the third embodiment of the method of production of an optical device according to the present invention continued from Fig. 6.

[Fig. 8]

A schematic explanatory view of a fourth embodiment of the method of production of an optical device according to the present invention.

[Fig. 9]

A schematic explanatory view of the fourth embodiment of the method of production of an optical device according to the present invention continued from Fig. 8.

[Fig. 10]

A schematic explanatory view of a fifth embodiment of the method of production of an optical device according to the present invention.

[Fig. 11]

A schematic explanatory view of a sixth embodiment of the method of production of an optical device according to the present invention.

[Description of References]

3... metallic mold, 3C... cavity, 4... passageway, 5, 5A, 8U, $8U_1$, $8U_2$, 20U... projections, 6, 11, 21, 31, 41, 51, 101... base materials, 6B, 6U, 7B, 10B, $10B_1$, $10B_2$, 20B, 101B, 27U, 31B, 31U, 41B, 41U, 51B, 51U, 71U,

101B, 101D... concavities, 6L, 6M, 7M, 10M, 11M, 20M, 21M, 27M, 31M, 37M, 41M, 47A, 47M, 51M, 57A, 57, 71M... optical materials, 7, 10, 10_1, 10_2, 20, 20_1, 20_2, 27, 37, 47, 57, 71... layers, 8, 8_1, 8_2, 18, 18_1, 18_2... silicon substrates, 9, 19, 19_1, 19_2... resists, 29, 39... resist films, 29H, 39H...windows, 32... etching solution, 100... optical device, 100B... lower face, 100U... upper face, 101C, 101E... flat portions, and 102, 103... lenses.

DOCUMENT NAME DRAWINGS

Fig. 1

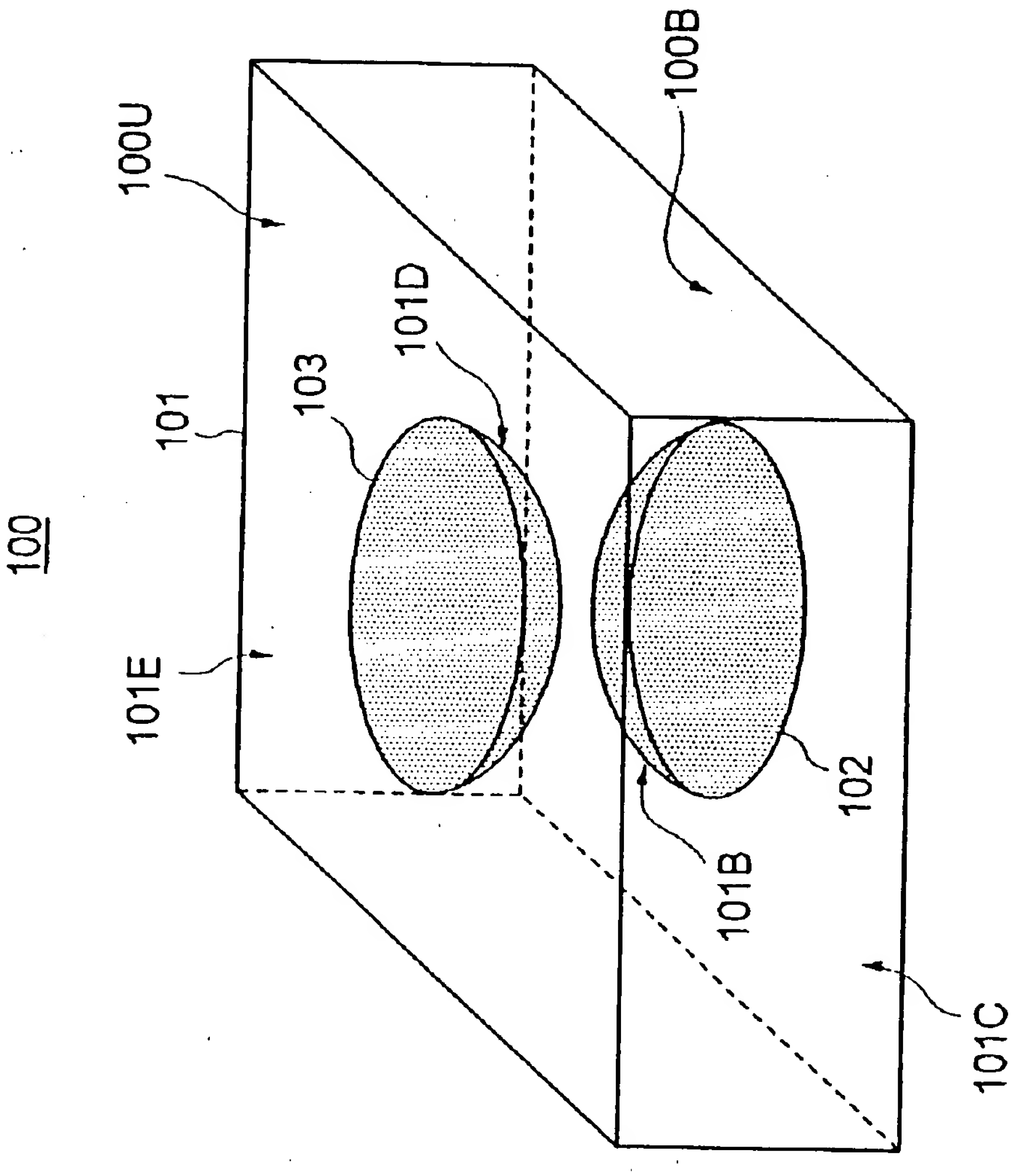

Fig. 2

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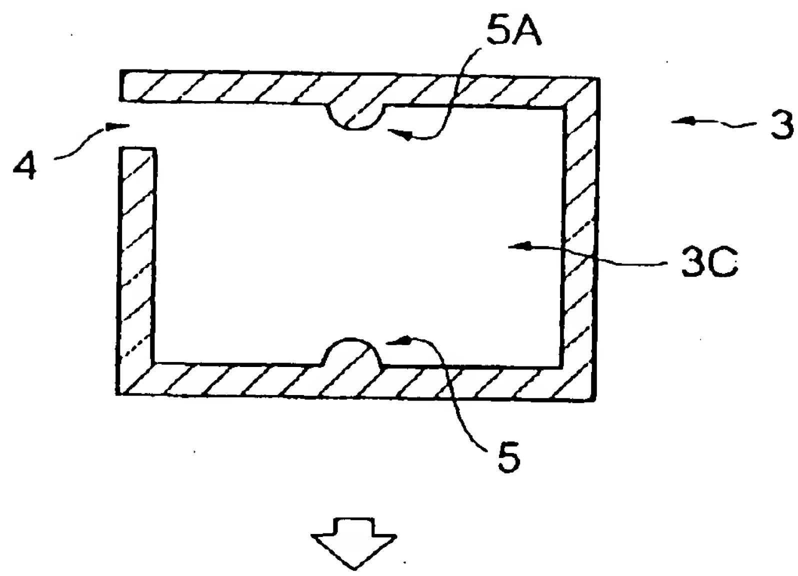

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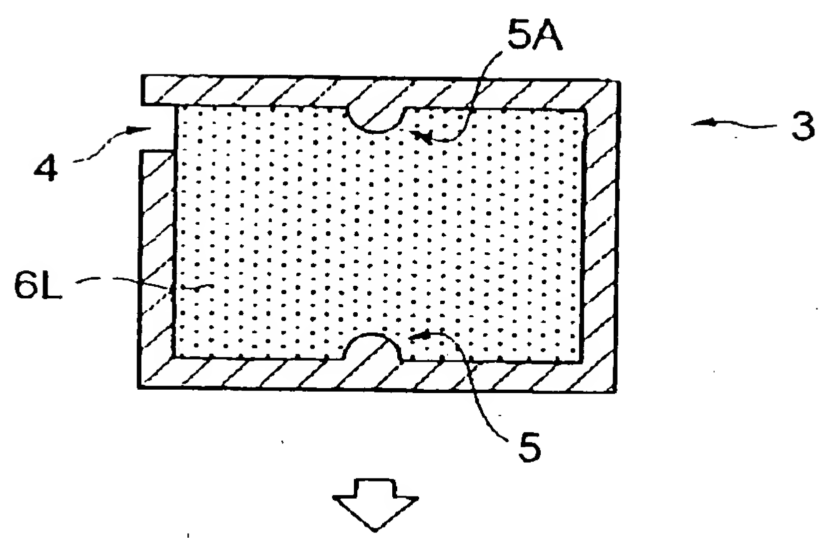

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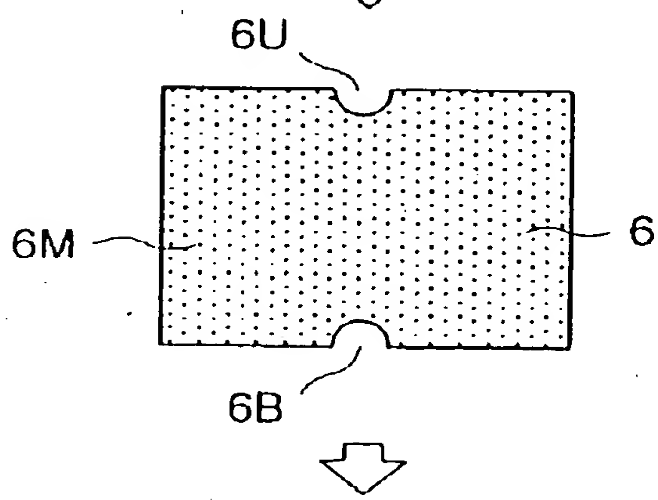
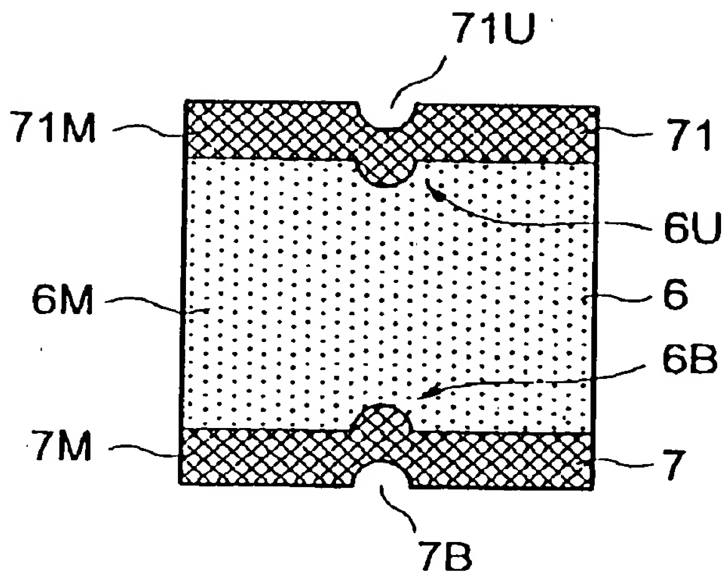


Fig. 3

(D)



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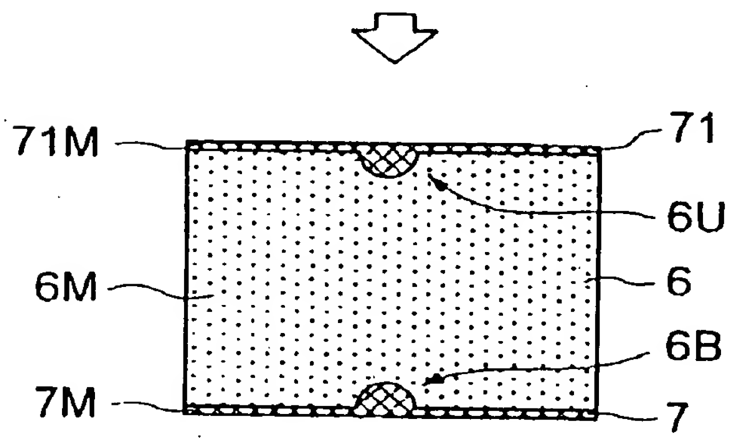

Fig. 4

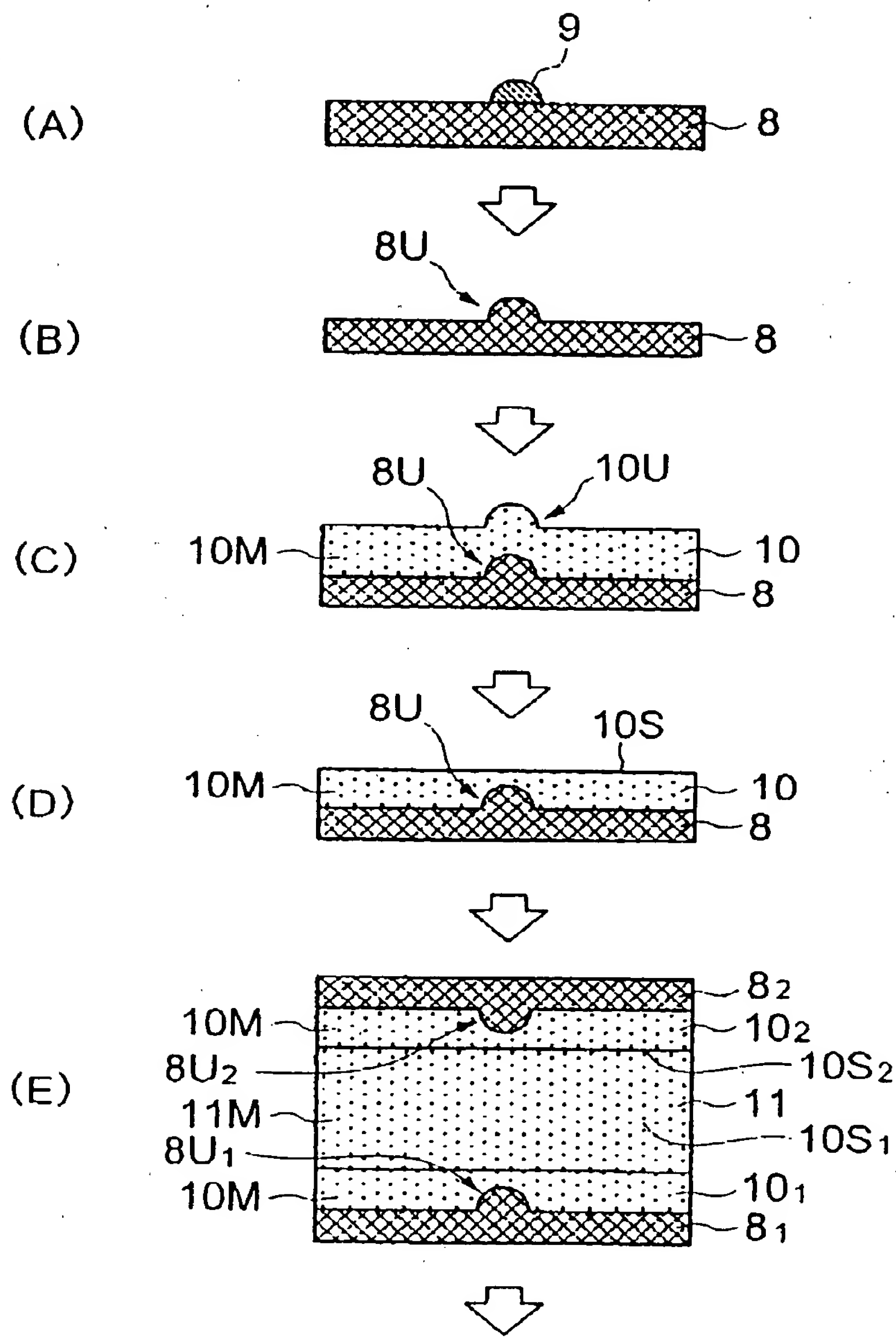
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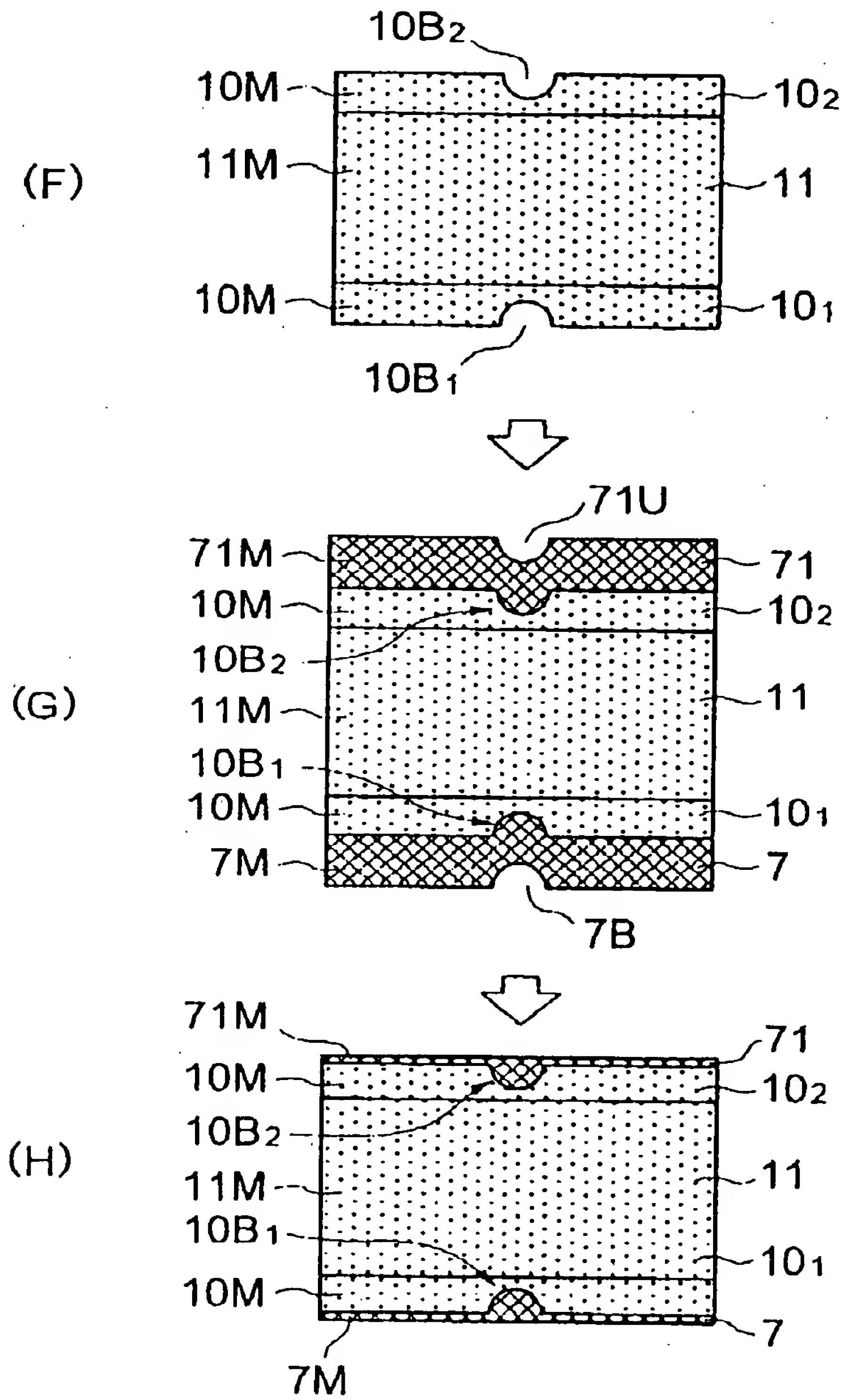
Fig. 5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101
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Fig. 6

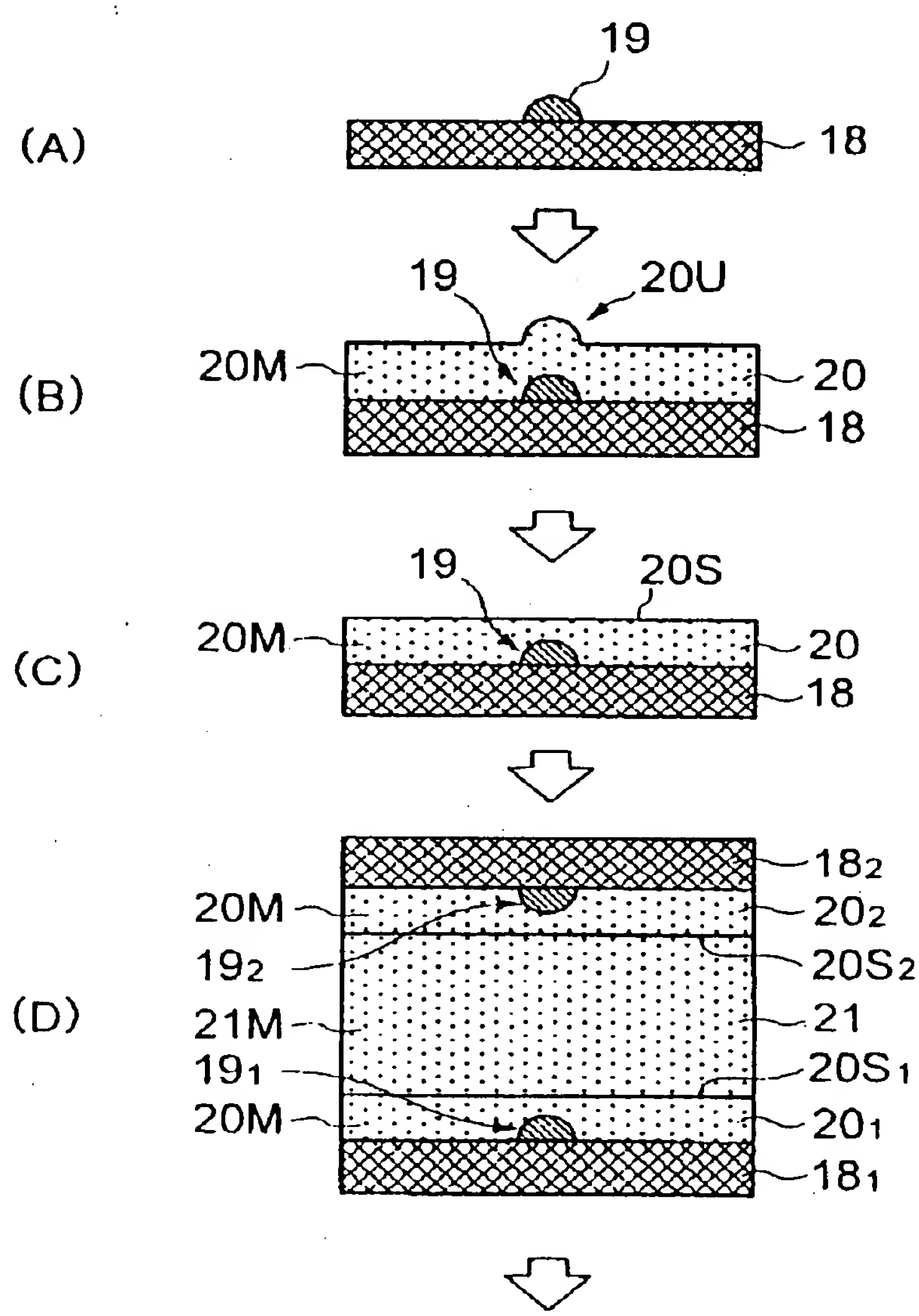
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Fig. 7

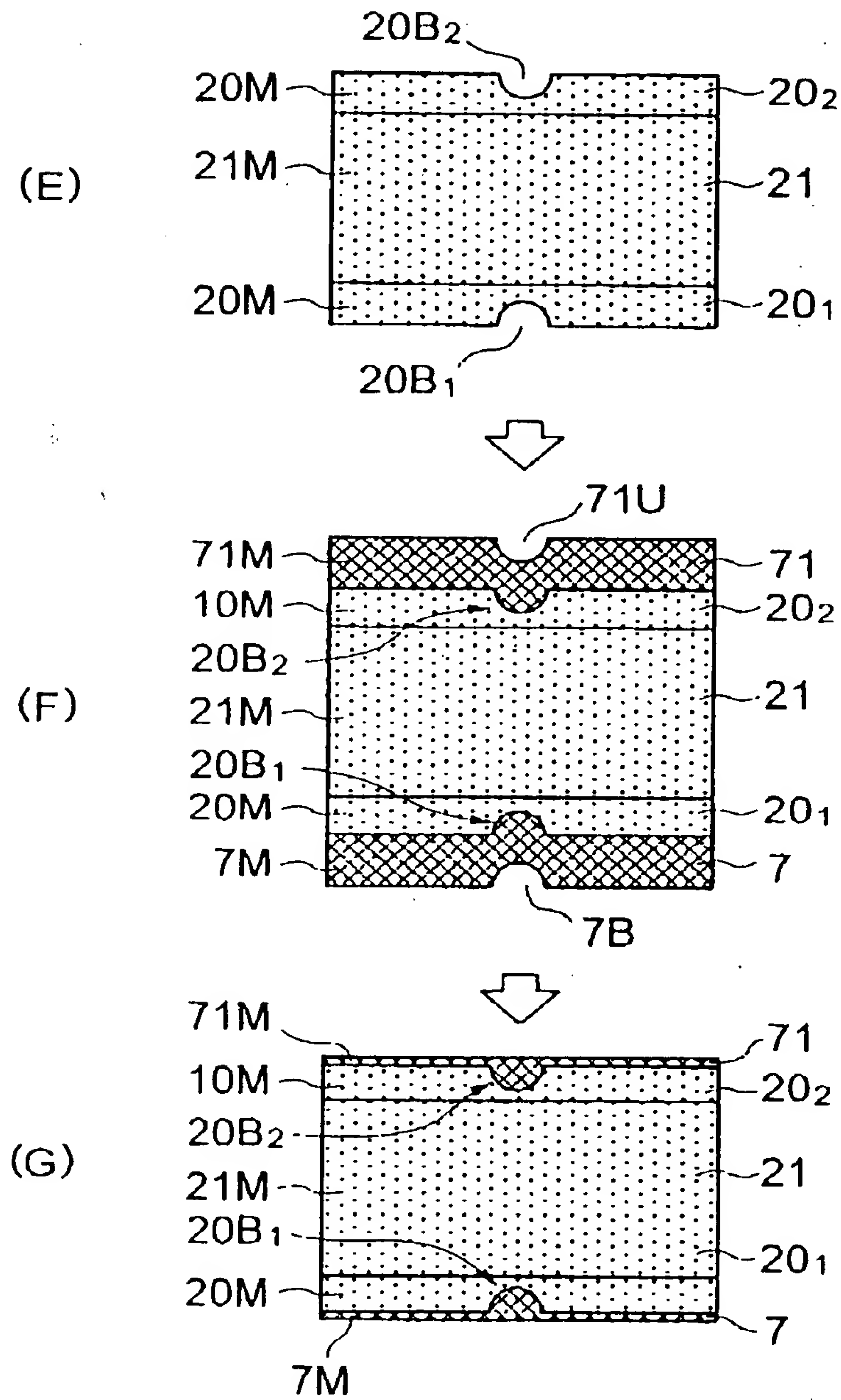
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Fig. 8

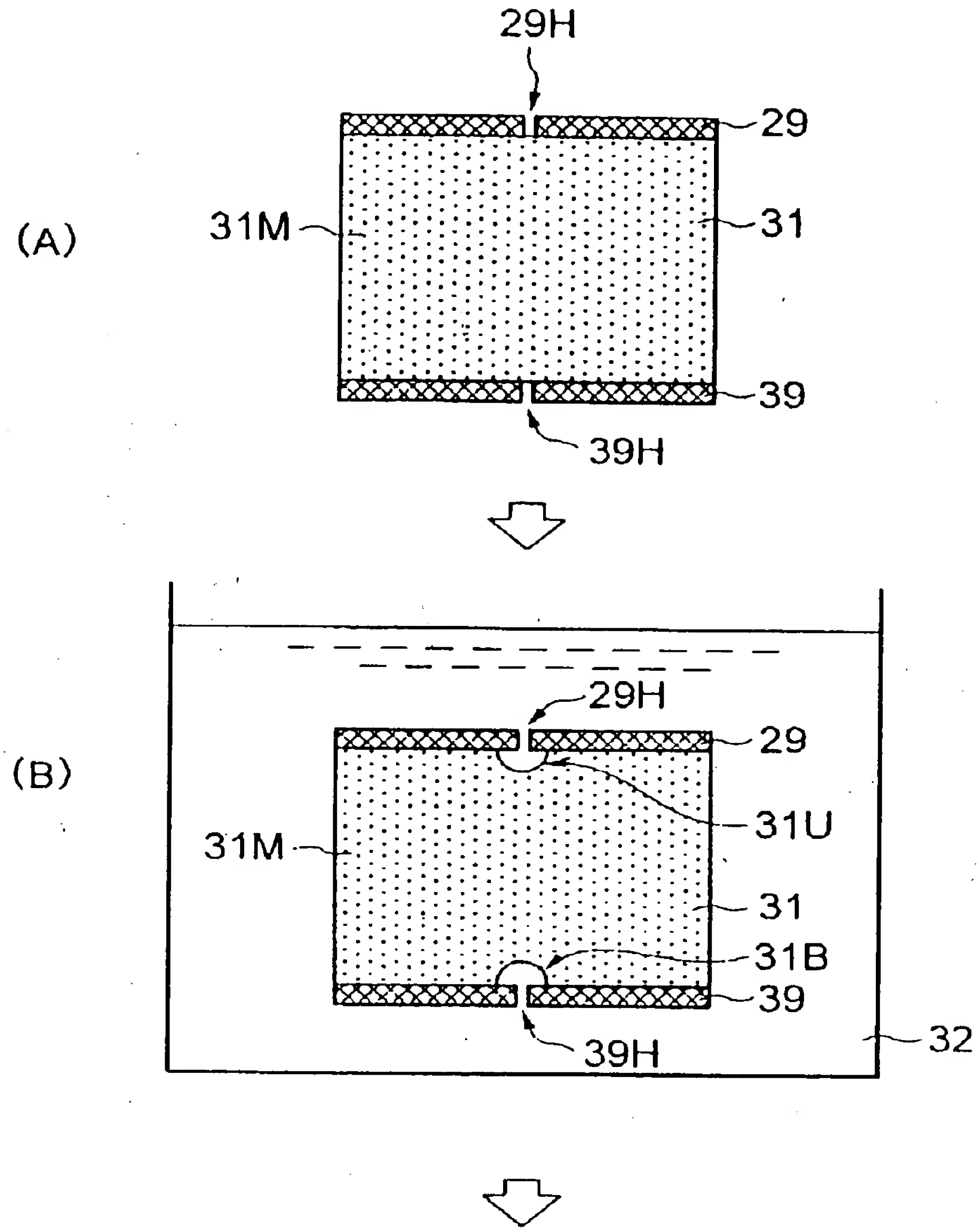

Fig. 9

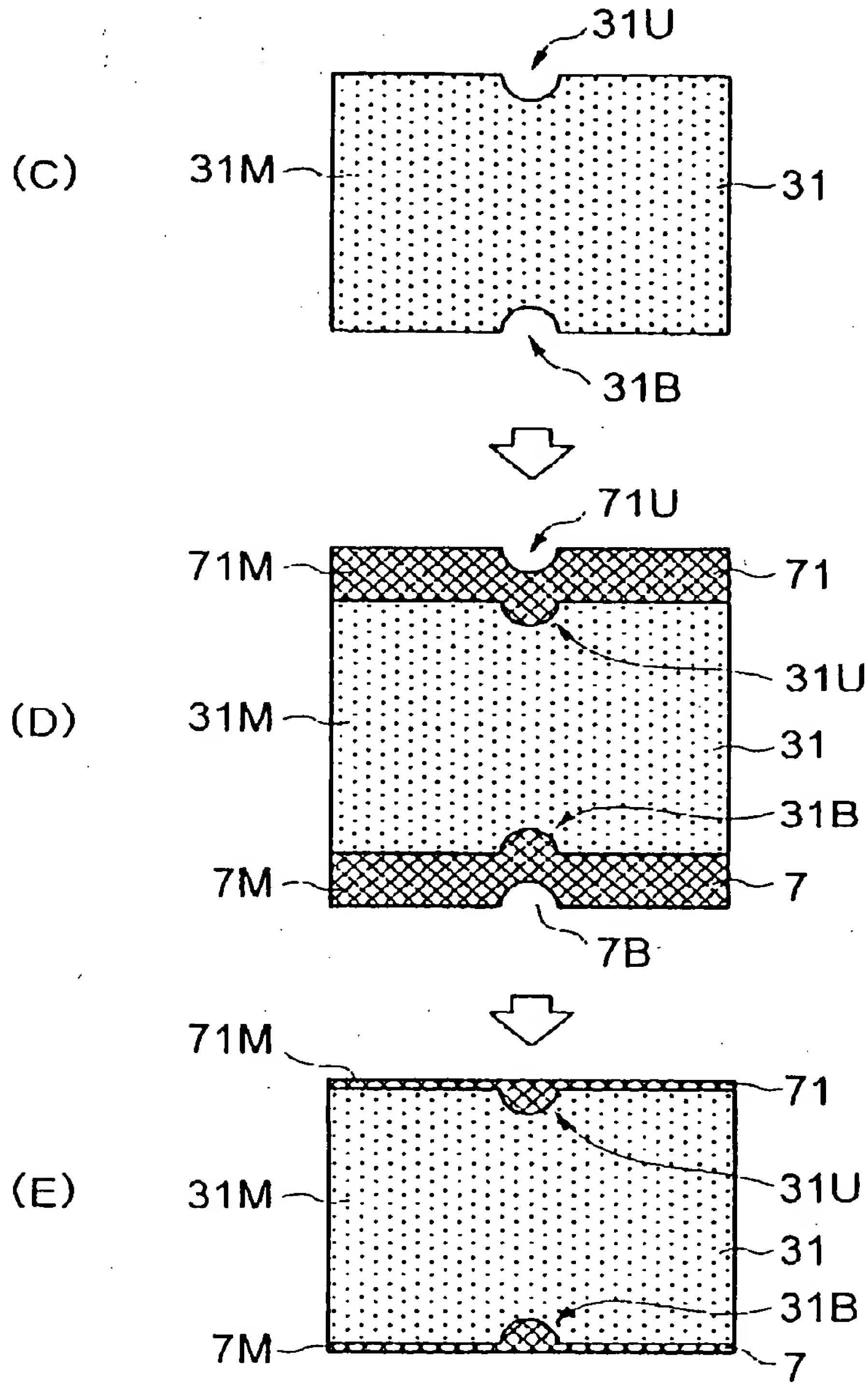
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Fig. 10

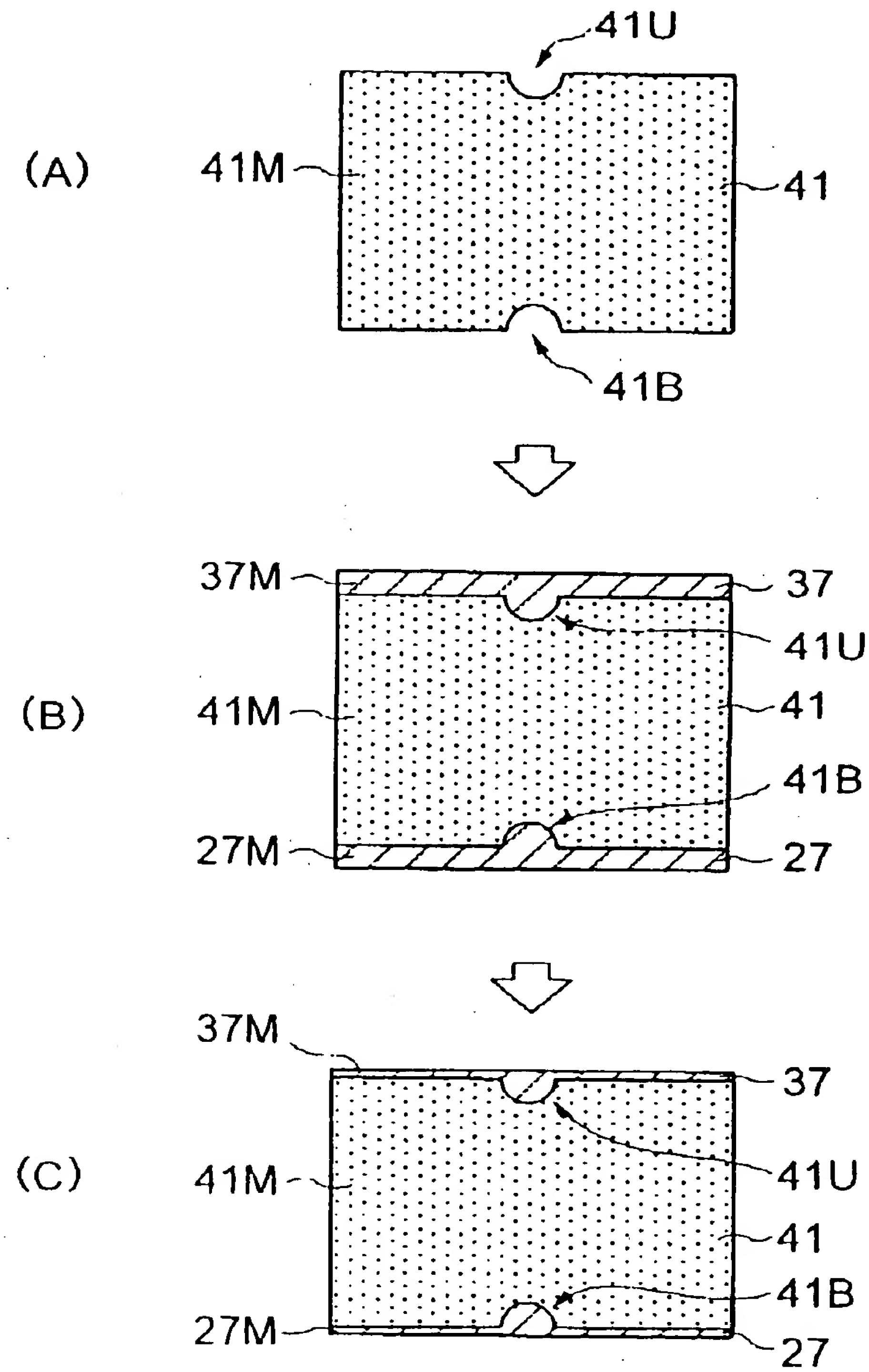
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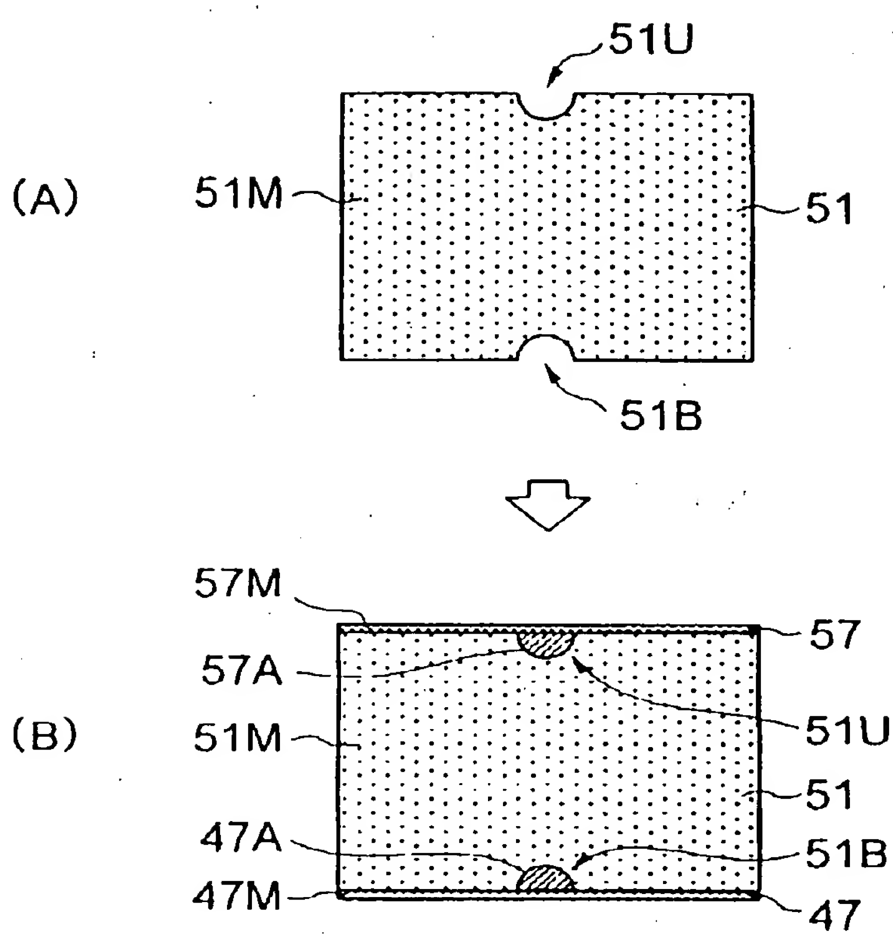
Fig. 11



[NAME OF DOCUMENT] Abstract

[ABSTRACT]

[PROBLEM] To provide an optical device having a small size and a large numerical aperture.

[MEANS FOR SOLUTION] An optical device 100 has a base material 101 made of a first optical material and has a second optical material having a different refractive index from the first optical material. The base material 101 has first and second faces 100B and 100U facing each other, a rotationally symmetric first concavity 101B is formed in the first face 100B, and a rotationally symmetric second concavity 101D is formed in the second face 100U. The second optical material is filled in the concavities 101B and 101D and comprise the lenses 102 and 103. For example, the first optical material is made quartz, and the second optical material is made silicon nitride (SiN) or gallium phosphate (GaP). By making the concavities 101B and 101D small, it is possible to reduce the sizes of the lenses 102 and 103, and it is possible to reduce the size of the optical device 100.

[SELECTED DRAWING] Fig. 1